Hadron Formation in DIS in a nuclear environment

Valeria Muccifora (on behalf of the HERMES Collaboration)
I.N.F.N. Laboratori Nazionali di Frascati, via E. Fermi 40 I-00044 Frascati, Italy
E-mail: valeria.muccifora@lnf.infn.it

The influence of the nuclear medium on the production of charged hadrons in semi-inclusive deep inelastic scattering has been studied by the HERMES experiment at DESY using 27.5 GeV positrons. A substantial reduction of the multiplicity of charged hadrons and identified charged pions from nuclei relative to that from deuterium has been measured as function of the relevant kinematic variables. The preliminary results on krypton show a larger reduction of the multiplicity ratio R_M^h with respect to the one previously measured on nitrogen and suggest a possible modification of the quark fragmentation process in the nuclear environment.[a]

1 Introduction

The understanding of quark propagation through the nuclear environment is crucial for the interpretation of ultra-relativistic heavy ion collisions and high energy proton-nucleus and lepton-nucleus interactions. Quark propagation in the nuclear medium involves competing processes like the hadronization of quarks, the quark energy loss through multiple scattering, and gluon radiation. Semi-inclusive deep inelastic lepton-nucleus collisions provide a unique opportunity to study these effects. In the simplest scenario, the nucleus, which has the size of a few fermi, acts as an ensemble of targets with which the struck quark or the formed hadron may interact. In contrast to proton-nucleus scattering, in deep inelastic scattering (DIS) no deconvolution of the distributions of the projectile and target fragmentation particles has to be made, so that hadron distributions and multiplicities from different nuclei can be directly related to nuclear effects in quark propagation and hadronization.

2 Experimental results

The experimental results are presented in terms of the multiplicity ratio R_M^h, which represents the ratio of the number of hadrons of type h produced per DIS event for a nuclear target of mass A to that from a deuterium target (D):

$$R_M^h(z,\nu) = \frac{\left.\frac{N_h(z,\nu)}{N_e(\nu)}\right|_A}{\left.\frac{N_h(z,\nu)}{N_e(\nu)}\right|_D} = \frac{\left.\frac{\sum e_f^2 q_f(x) D_f^h(z)}{\sum e_f^2 q_f(x)}\right|_A}{\left.\frac{\sum e_f^2 q_f(x) D_f^h(z)}{\sum e_f^2 q_f(x)}\right|_D}. \tag{1}$$

[a]Proceeding of DIS 2001, IX International Workshop on Deep Inelastic Scattering Bologna, 27 April-1 May 2001

Here z represents the fraction of the virtual photon energy ν transferred to the hadron, $N_h(z,\nu)$ the number of semi-inclusive hadrons in a given (z,ν)-bin, $N_e(\nu)$ the number of inclusive DIS leptons in the same ν-bin. This ratio can be expressed in term of the fragmentation functions $D_f^h(z)$ of a quark of flavor f, and the quark distribution functions $q_f(x)$, with x the Bjorken scaling variable.

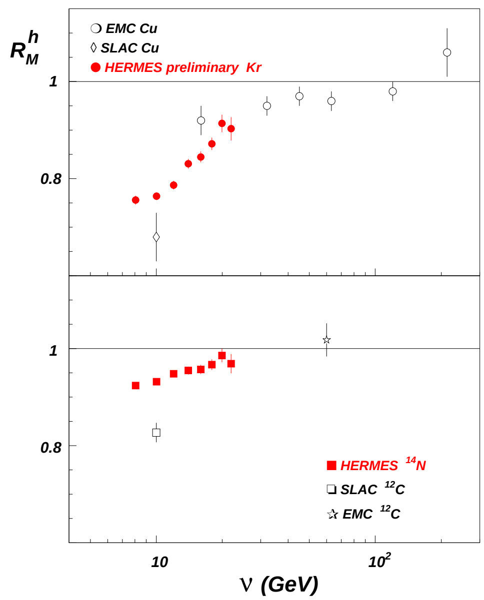

Figure 1: Charged hadron multiplicity ratio R_M^h as a function of ν for values of z larger than 0.2. The error bars represent the statistical uncertainty only.

The multiplicity ratio has been measured at HERMES using D, ^{14}N and ^{84}Kr gas targets internal to the 27.5 GeV HERA positron storage ring, by identifying both the scattered positron and the produced hadrons in the HERMES spectrometer [1]. The HERMES results [2] for the multiplicity ratio for all charged hadrons with $z > 0.2$ are presented as a function of ν in Fig. 1 together with data of previous experiments on nuclei of similar size [3,4]. The HERMES data for R_M^h are observed to increase with increasing ν and are consistent with the high-energy EMC data. In particular, the preliminary ^{84}Kr data show that the HERMES energy range is well suited for the study of quark propagation and hadronization. The energy dependence of the data follows the expectations of the gluon-bremsstrahlung model of hadronization [5,2]. A stronger attenuation is observed for ^{84}Kr with respect to ^{14}N with an increase in the average attenuation of a factor of about 3.7. This value is

in reasonable agreement with the predicted modifications of the quark fragmentation functions in DIS [6], that are expected to depend quadratically on the nuclear size. The behaviour of the ^{14}N and the ^{84}Kr data is consistent when plotted as a function of the relevant kinematic variables, as shown in Fig. 2 where the multiplicity ratio for charged hadrons with $\nu > 7$ GeV is given as a function of z and of the hadron transverse momentum square p_t^2. The stronger decrease with z observed for the ^{84}Kr with respect to the ^{14}N follows the expectations of the medium-modified fragmentation function [6]. A

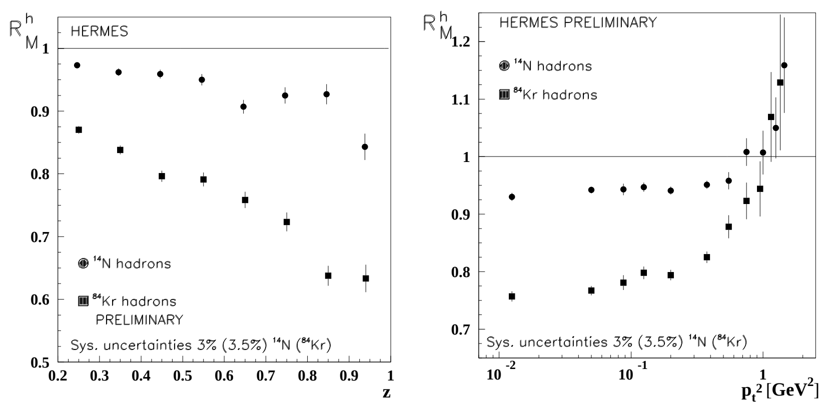

Figure 2: The multiplicity ratio for charged hadrons (left) versus z and (right) versus p_t^2.

nuclear enhancement at high p_t^2 is observed from the HERMES data, similar to the one reported for proton-nucleus and nucleus-nucleus collisions which is known as the Cronin effect. The Cronin effect has been explained in the framework of multiple parton scattering. Within the Glauber formalism [7] the transition between soft and hard processes is predicted to occur at a scale of $p_t \sim$ 1-2 GeV in agreement with the data of Fig. 2. The multiple scattering process is directly associated with multiparton correlation functions. It has been shown [8] that the transverse momentum broadening of leading pions in deep inelastic lepton-nucleus scattering is an excellent observable to probe the parton correlation functions in the nucleus, and that a measurement of the dependence of the transverse momentum enhancement provides information on the functional form of the parton correlation functions. The HERMES results shown in Fig. 2 seem to suggest a nuclear-size dependence of the transverse momentum enhancement. The results presented thusfar concern the sum of positive and negative hadrons. For both hadrons and pions the multiplicity ratios have been separately determined for the two charge states. Pions were identified in the momentum range between 4 and 13.5 GeV by using a RICH

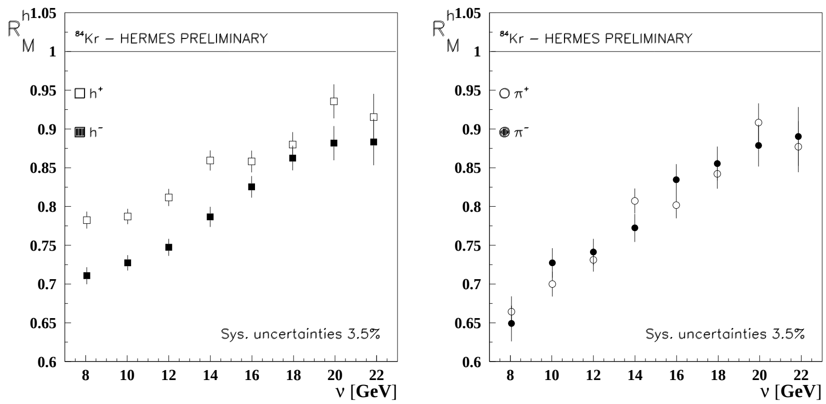

Figure 3: Multiplicity ratios for hadrons including pions (left) and identified pions (right) as a function of ν. The open (closed) symbols represent the positive (negative) charge states.

detector. In the left (right) panel of Fig. 3, the multiplicity ratios for positive and negative hadrons (pions) are displayed as a function of ν for ^{84}Kr. The data show that the multiplicity ratio is the same for positive and negative pions while a significant difference is observed between R_M^h for positive and negative hadrons. This result, that agrees with the one reported for the ^{14}N data [2] obtained with a threshold Čerenkov detector, can be interpreted in terms of a difference between the formation time of protons and pions. Alternatively, it has been suggested that the observed differences between positive and negative hadrons can be attributed to a different modification of the quark and antiquark fragmentation functions in nuclei [9]. In order to clarify this issue an analysis has been started of multiplicity ratios for identified kaons, protons and anti-protons in various nuclei using the RICH detector at HERMES.

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